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Monitoring of Bolt Axial Load**

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EVALUATION OF ROCK SUPPORT PERFORMANCE THROUGH INSTRUMENTATION AND MONITORING OF BOLT AXIAL LOAD

Hani Mitri

ABSTRACT: A practical method for the estimation of roof bolt axial loads in the field as a means for evaluating rock support performance in underground mine openings such as drifts and gate roads is presented. The method is based on attaching an instrumented coupler to the bolt head prior to installation. Once installed, the coupler load cell enables the Measuring and monitoring of the bolt axial force exerted on the face plate. Previously developed load cell technologies for rock anchors are reviewed, and their design deficiencies for applications in underground mining are highlighted. On the other hand, the instrumented coupler technique is shown to provide a simple and practical means for the evaluation of rock support performance in mine openings.

INTRODUCTION

The consequences of rock falls in underground mines can be disastrous. Rock falls can cause mine production delays, and can be responsible for serious injuries and even fatalities. Therefore much attention is given to the design and installation of adequate rock support systems. Rock supports such as mechanical rockbolts and resin grouted rebars are installed in almost all mine access areas such as gate roads, drifts, ramps and shafts. Because of their important role as primary rock support, it is necessary to verify that the rockbolt is functioning adequately and is not subjected to excessive load. There are many situations where such a concern may arise especially in development and production areas where the ground response changes constantly due to mining induced stress changes.

The need to measure the rockbolt load with instrumentation methods has been recognized by researchers and new measurement techniques were successfully developed and became commercially available. One of such products is the vibrating wire hollow load cell technology shown in Figure 1. As the load cell is sandwiched between the face plate and the reaction plate, it measures the axial strain inside the cell, from which the axial bolt load is calculated. The disadvantages of this technology are numerous: a) the vibrating wire strain gauge is fragile and often breaks prematurely as it reaches its limit of 2500 to 3000 μs , which is often not enough to ensure the measurement of the bolt yield load; b) the face and reaction plates must be placed perfectly perpendicular to the bolt to capture the correct reaction force, which is not always possible in mining applications; c) the hollow load cell reduces the headroom of the gate road by at least 15 cm; d) surface preparation is required to make sure that the surface and reaction plates are perfectly parallel.

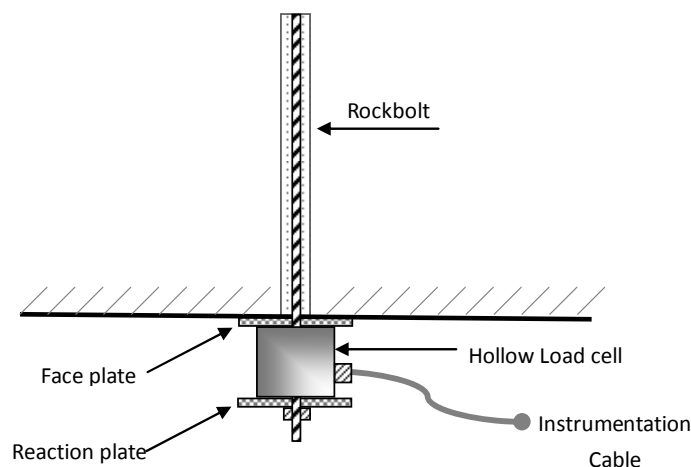


Figure 1 - Design concept of the hollow load cell

INSTRUMENTED ROCKBOLT

To overcome the drawbacks associated with the use of the hollow load cell technology, Mitri and Marwan (2001) proposed a design that is based on placing a strain gauge directly in the bolt head by drilling a central blind hole that extends beyond the threaded portion as shown in Figure 2. As the strain gauge is placed in the axial direction, it measures the load induced axial strains, which can be converted to bolt axial load. Unlike the hollow load cell, the embedded strain gauge in the bolt head requires no additional headroom in the drift, and does not require any surface preparation.

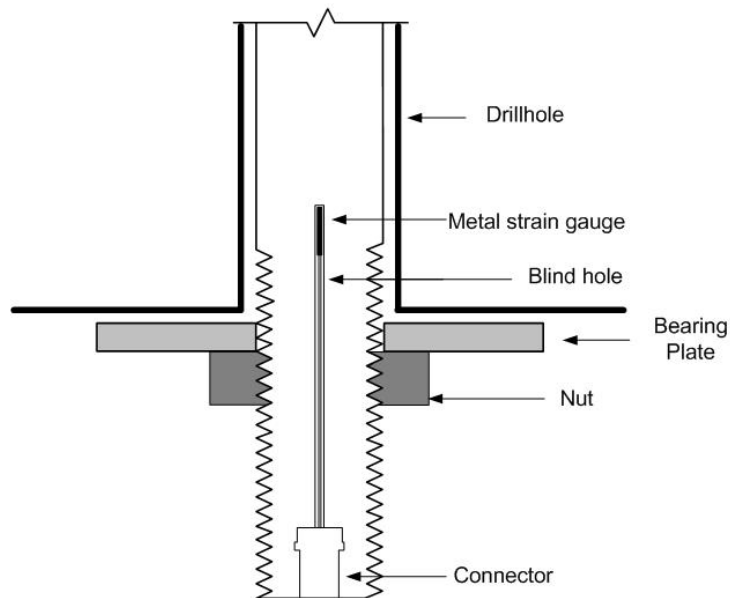


Figure 2 - Rockbolt load cell design concept proposed by Mitri and Marwan (2001)

Thus, this technique is not prone to erroneous measurements due to the position of the face plate with respect to the rock surface. Moreover, the metal-based strain gauge has a stretch capacity that is much greater than the vibrating wire strain gauge used with the hollow load cell. Thus, with this design, it is possible to measure the bolt yield load as the strain limit of the metal gauge is larger than the yield strain of the bolt steel material.

It can be seen that this technique is applicable to virtually any type of rock anchor such as mechanical rock bolt, cone bolt, grouted rebar, and forged head bolt. Mitri and Laroche (2004) report the application of this technique in Canadian hard rock mines. Recognizing the need to protect the head connector during transport of the bolt, a protective cap was designed as shown in Figure 3. Mitri and Marwan (2001) and Mitri and Laroche (2004) give more details of this concept.

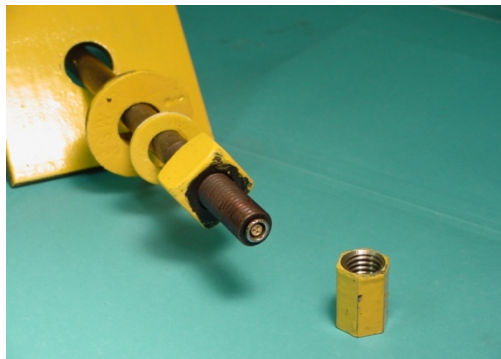


Figure 3 - Photo of protective metal caps placed on instrumented bolts (Mitri and Laroche, 2004)

In spite of the above mentioned features, the instrumented bolt design has some drawbacks that limit its suitability to mining applications. One deficiency of this design is the need to transport the bolt back and forth to the mine. This results in additional materials handling work and cost. It also exposes the head connector to damage during shipping and handling. Another deficiency is that the hole drilled in the bolt

head reduces its capacity by about 3%. The gauge being installed in the bolt itself is thus unable to measure the ultimate or breaking strength of the rock bolt. Most rock anchors have an ultimate strength that is 10% - 15% greater than the yield load. Thus, it can be said that even if the bolt load reaches the yield limit, it can still offer further load supporting capability before it eventually breaks. It is worth noting that most reported bolt failures occur at the end of the threaded section where the cross sectional area is the least. Snapping of the threaded bolt head in this fashion is due to excessive load at the bolt head and is not uncommon in underground mines near active mine production areas.

INSTRUMENTED COUPLER LOAD CELL

While the design concept of the instrumented rockbolt offers unique advantages over the traditional hollow load cell technology, it is nevertheless not practical for mining applications because of the design deficiencies mentioned above. To overcome such deficiencies, the author proposed a new concept for monitoring axial load on the bolt head was proposed (Mitri, 2011). The new concept, illustrated in Figure 4, is made of a coupler instrumented with a metal strain gauge that is placed in the blind borehole along the axis of the coupler. The coupler load cell is fitted onto the rock anchor, which, once installed in the rock, permits the monitoring of the anchor head axial load. The advantages of this new design concept are numerous. The coupler is designed so that its yield load is greater than the ultimate breaking strength of the rock anchor. This design ensures a complete load path monitoring of rock support performance until failure. The coupler design offers the advantages of light weight in shipping and handling as well as ease of installation in the field. As shown in Figure 4, the upper end of the coupler load cell is a threaded hole that is tapped to fit the desired thread diameter of the rock anchor.

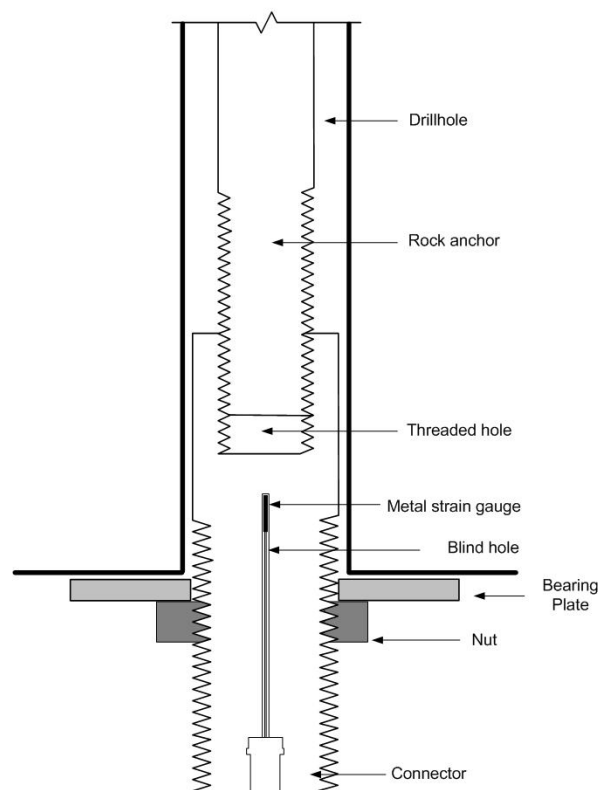


Figure 4 - New coupler load cell design concept

DATA ACQUISITION

The instrumented coupler load cell circuit design is based on the well-known Wheatstone Bridge. Therefore, a wide range of data acquisition systems can be used to record the bridge output for a given load. The coupler load cell is first calibrated under axial loads ranging up to 50% of the elastic limit of the target rock anchor for it is designed. The calibration chart provides a linear relationship between the axial load (in the desired units) and the Wheatstone Bridge output in mill volts is shown Figure 5. This type of calibration allows the instrumented coupler load cell to be connected to an existing data acquisition system in the mines.

Possible options for load monitoring include a) portable strain gauge reader, b) data logger, c) internet-connected data logger, and d) wireless transmission of data. When a portable strain gauge reader is used, the calibration chart is provided in units of load versus microstrain. The use of portable units is simple and practical in areas that do not require continuous load monitoring. The advantage of data loggers is that they provide load data regularly at a uniform time interval specified by the operator, e.g. one hour. Also, the data logger can be made multi-channel, and typically can monitor 4 bolts at a given location. Data stored in the data logger can be downloaded periodically on a laptop computer underground. Alternatively, the data logger may be connected to an Ethernet cable, if available at the mine, to transmit the load data to a computer on surface. Another option is when the data logger is equipped with a WiFi modem/antenna, whereby the recorded data is transmitted remotely. In all of the aforementioned methods, an instrumentation wire is used to connect the coupler load cell to either the portable readout unit or the data logger. For more information, the reader is referred to the <http://www.yieldpoint.com> of YieldPoint Inc.

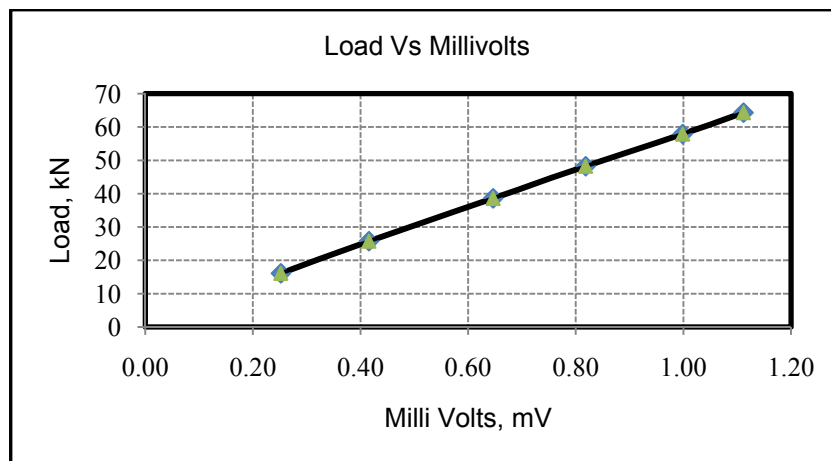


Figure 5 - Typical calibration test result of a coupler load cell

APPLICATIONS

The new coupler load cell has been applied to a variety of rock anchors in different mining applications. Figure 6 shows a typical load cell used to monitor No. 6 (3/4 inch) rebar. The outer nut serves as a jamming nut to enable the bolt spinning to puncture the resin cartridges and allow for mixing. Once the fast resin sets, the outer nut is removed and the bolt is tightened.



Figure 6 - Typical load cell mounted on a rebar

CONCLUSIONS

This is a new method of monitoring axial loads in rock anchors like rock bolts and rebars used as rock supports in underground mine drifts and roadways is presented. It has been shown that conventional hollow cell load technology is not suitable for mining applications. The author developed an alternative method that instruments the bolt head directly. However, such method deemed not practical due to the need to ship and handle the instrumented bolt from and to the mine. The new method, based on a coupler

load cell concept, is shown to be simple, practical and efficient. The instrumented coupler load cell technique is universal in the sense that it can be adapted to any type of rock anchor.

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